Symposium in honor of Owen Chamberlain's 75th Birthday

Phase-Space Cooling of Antiprotons

July 8, 1995,
Pimentel Hall,
University of California at Berkeley
Berkeley, California

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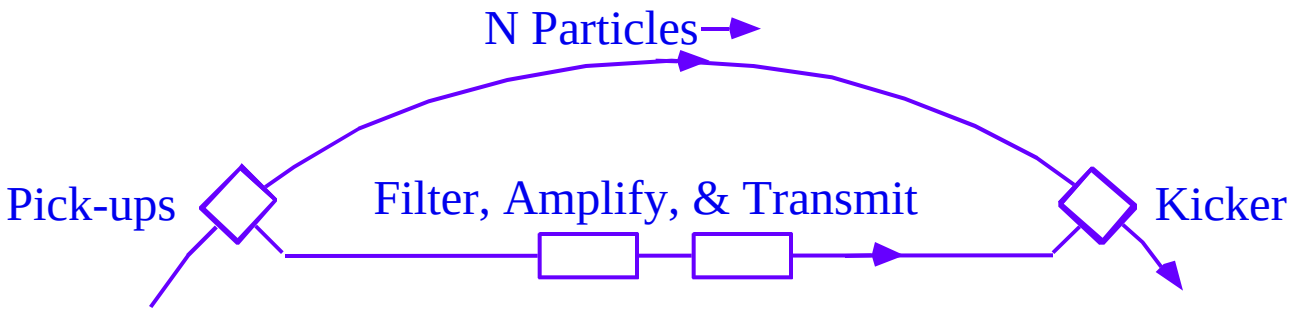
The Beam Cooling Scheme



$\sim 10^{-19}$ watt/particle

$\sim 10^{-11}$ watt/10^{8} particles

+ noise

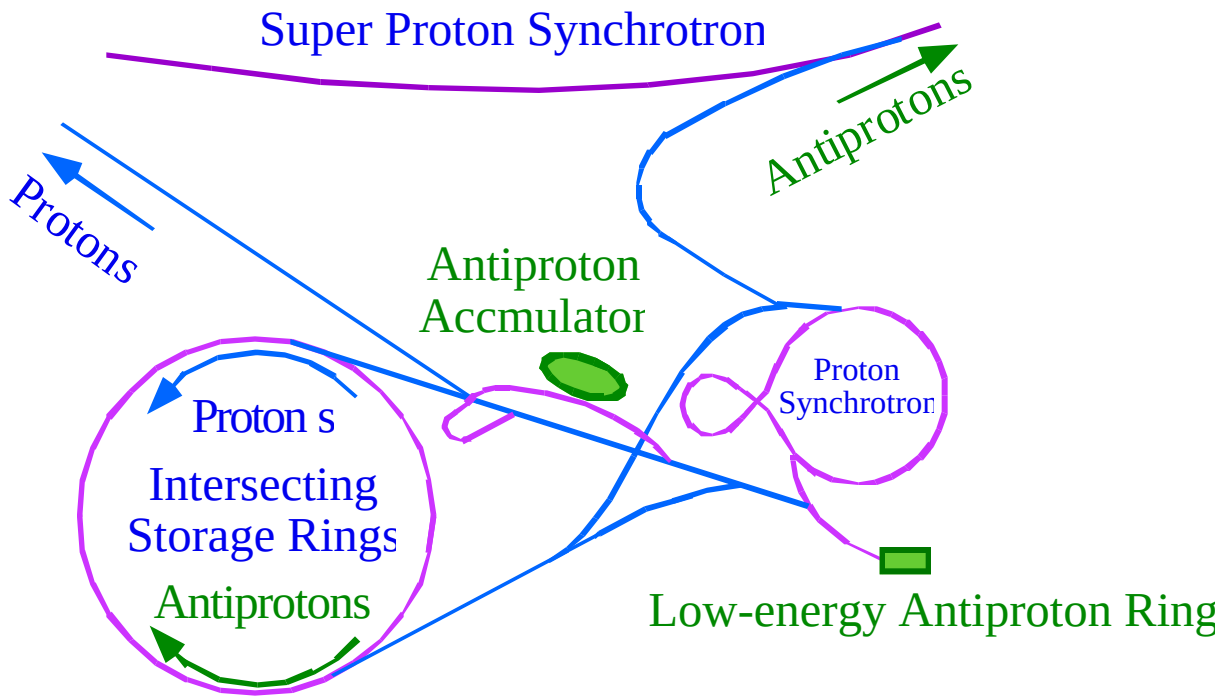
gain $\sim 10^{13}$

BW $\sim 10^{9}$ Hz

$\sim 10^{2}$ watt

Signal/Noise ~ nV/μV

CERN p-$\bar{p}$ Collider as it looked in 1982



An important discovery is marked by the number of significant avenues of human pursuit opened up by it leading to further inventions and discoveries
and so on .... !

Thank you, Owen !!

Cooling Rate

$$\frac{1}{\tau} = -\frac{1}{\varepsilon}\frac{d\varepsilon}{dt} \approx \frac{W}{N}\left[2G - G^2(\Gamma + \eta)\right]$$

COOLING

HEATING

SCHKOTTKYNOISE

THERMAL NOISE/SIGNAL

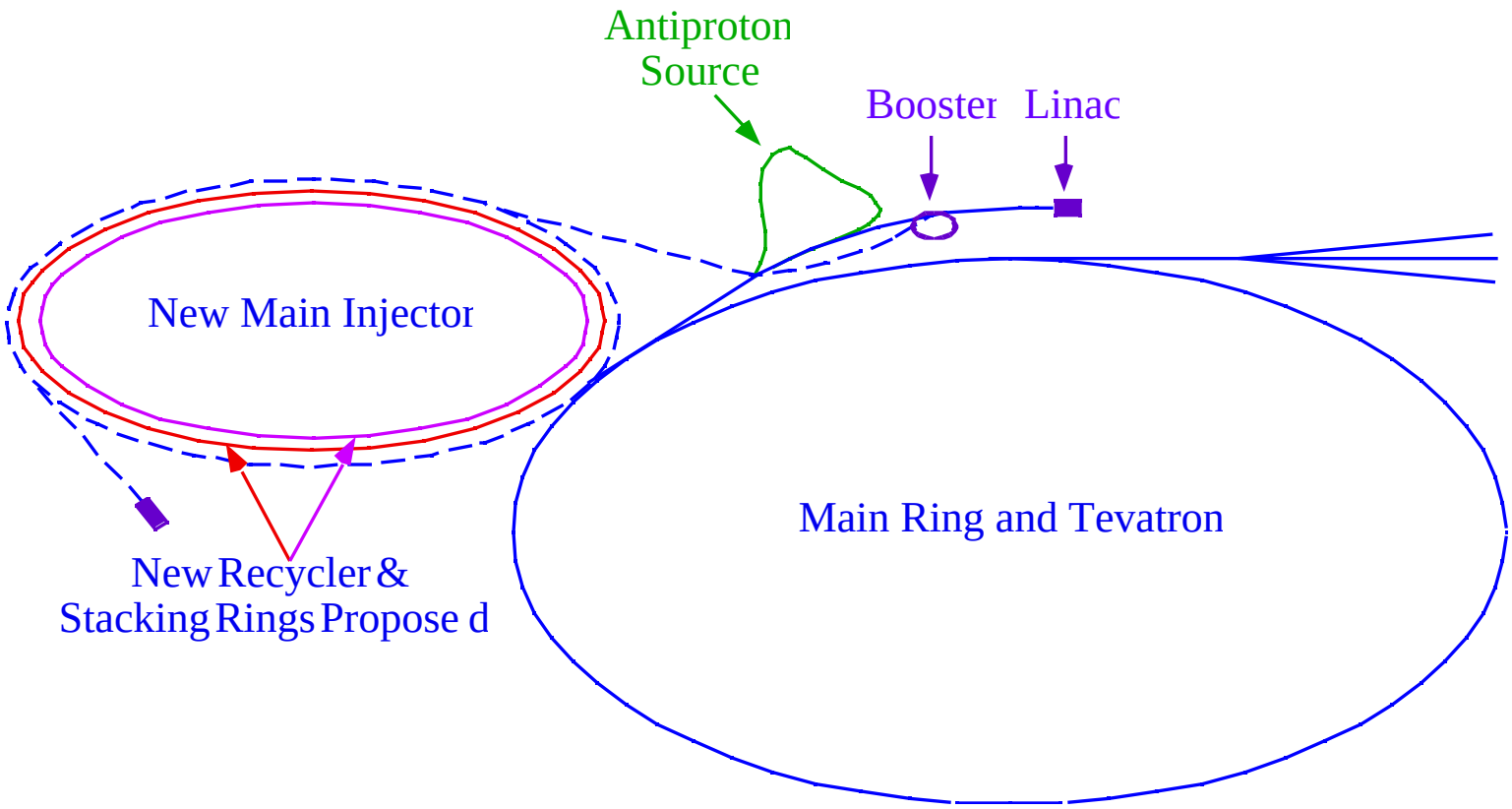
For optimized gain, G:

$$\frac{1}{\tau} \approx \frac{W}{N}\left[\frac{1}{(\Gamma + \eta)}\right]$$

Discovery of Antiprotons

- Confirms the 'reality' of Antimatter
- Possibility of producing Anti-Hydrogen in the laboratory
- ☞ Possibility of packing antiprotons into directed beams by phase-space cooling
- ☞ Possibility of proton-antiproton colliding beam physics
  - ☞ $p\bar{p} \longrightarrow$ Discovery of the Intermediate Vector Bosons, Z^o, $W^{\pm}$ (CERN), 1983
    - $\longrightarrow$ Establishing the existence of the Top Quark, (FNAL), 1995
    - $\longrightarrow$ Low mass Higgs in TeV * ??
- ☞ Where has all the Antimatter gone? CP Violation and Asymmetric B-Factories

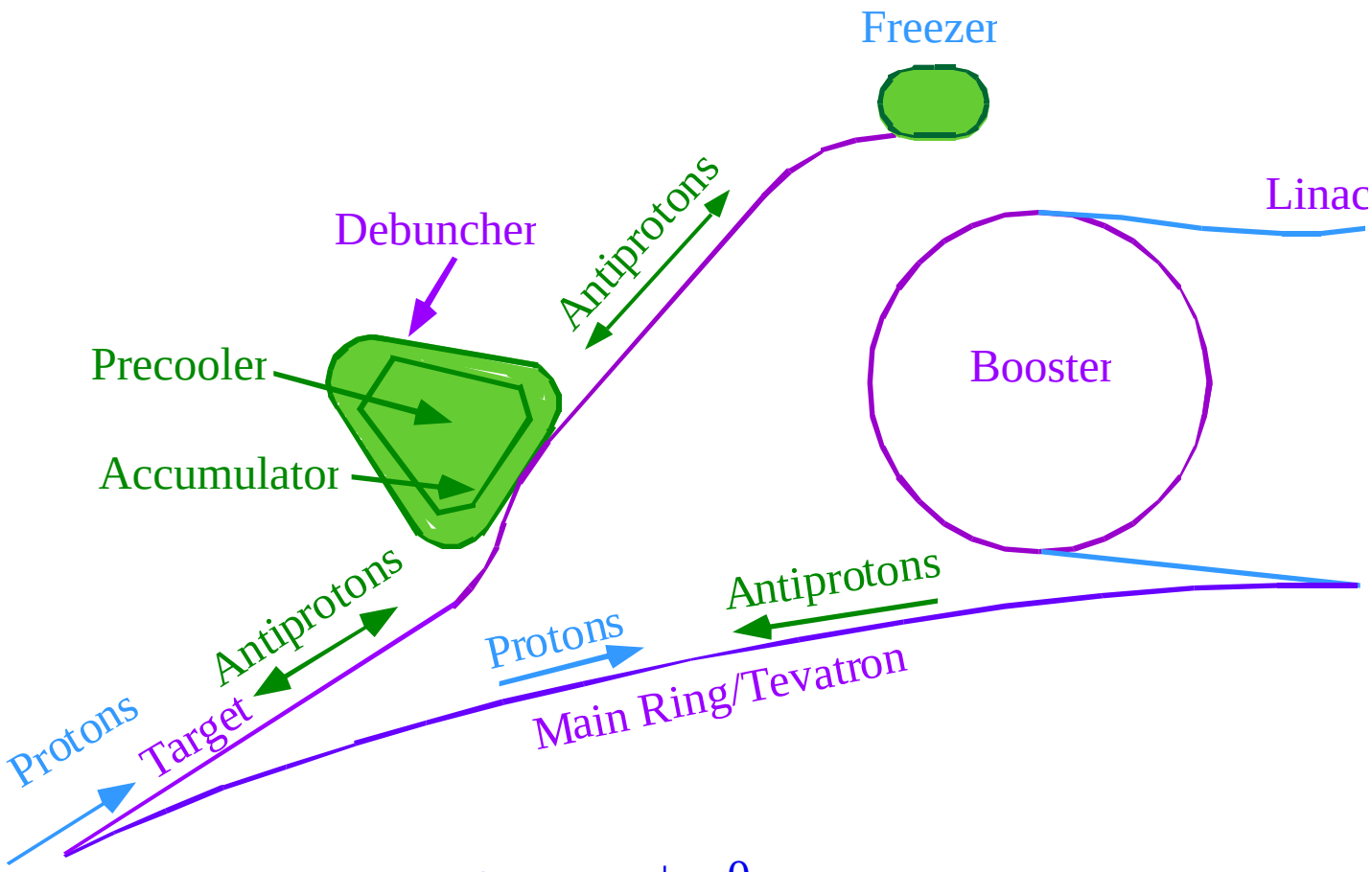
Fermilab Accelerator as it looks in 1995: TeV*



Integrated Luminosity ~10fb^{-1} → Low mass Higgs, if it exists

→ Rule out Supersymmetry, if no SUSY discoveries

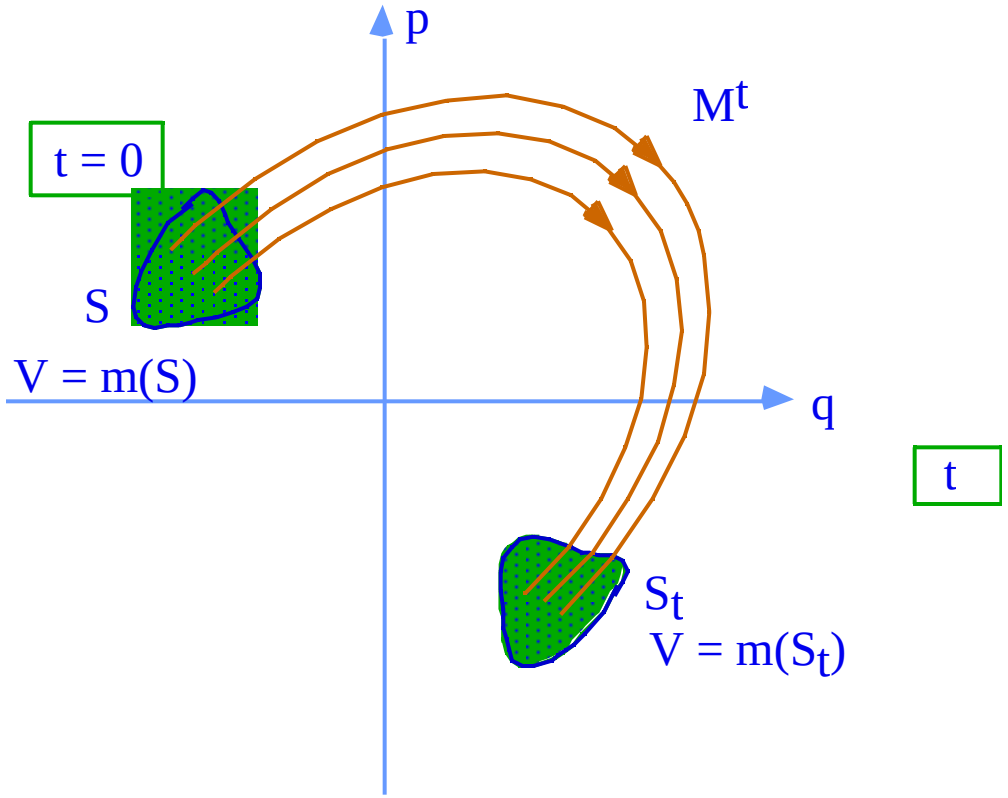
Fermilab p-$\bar{p}$ Collider as it looked in 1982



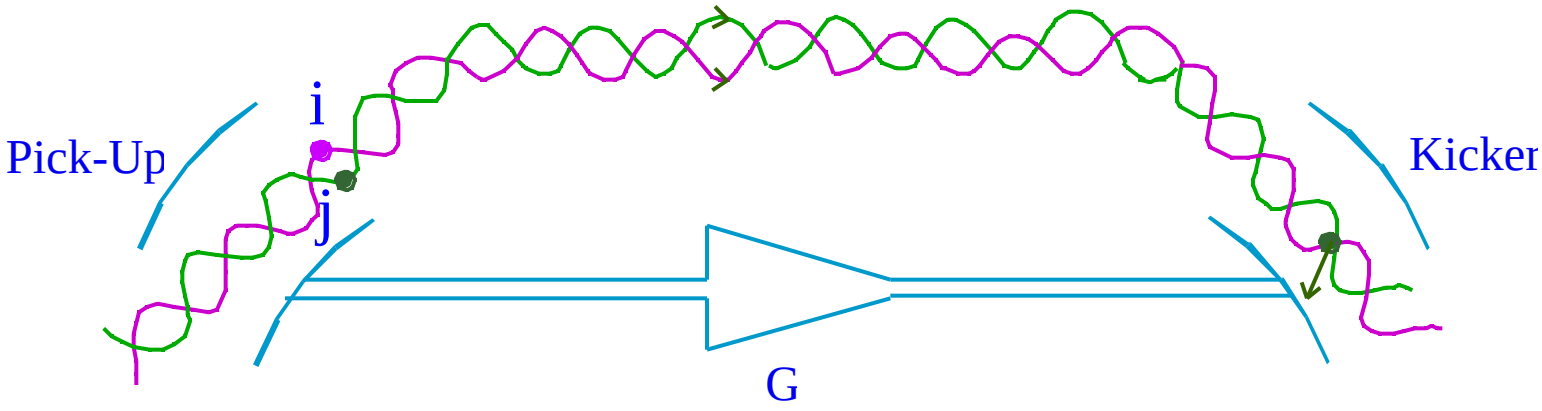
Confirmed $W^{\pm}$, Z^0 in 1984 and
discovery of Top Quark, 1995

Hamiltonian Mapping Generating Incompressible Liouvillian Flow in Phase-Space

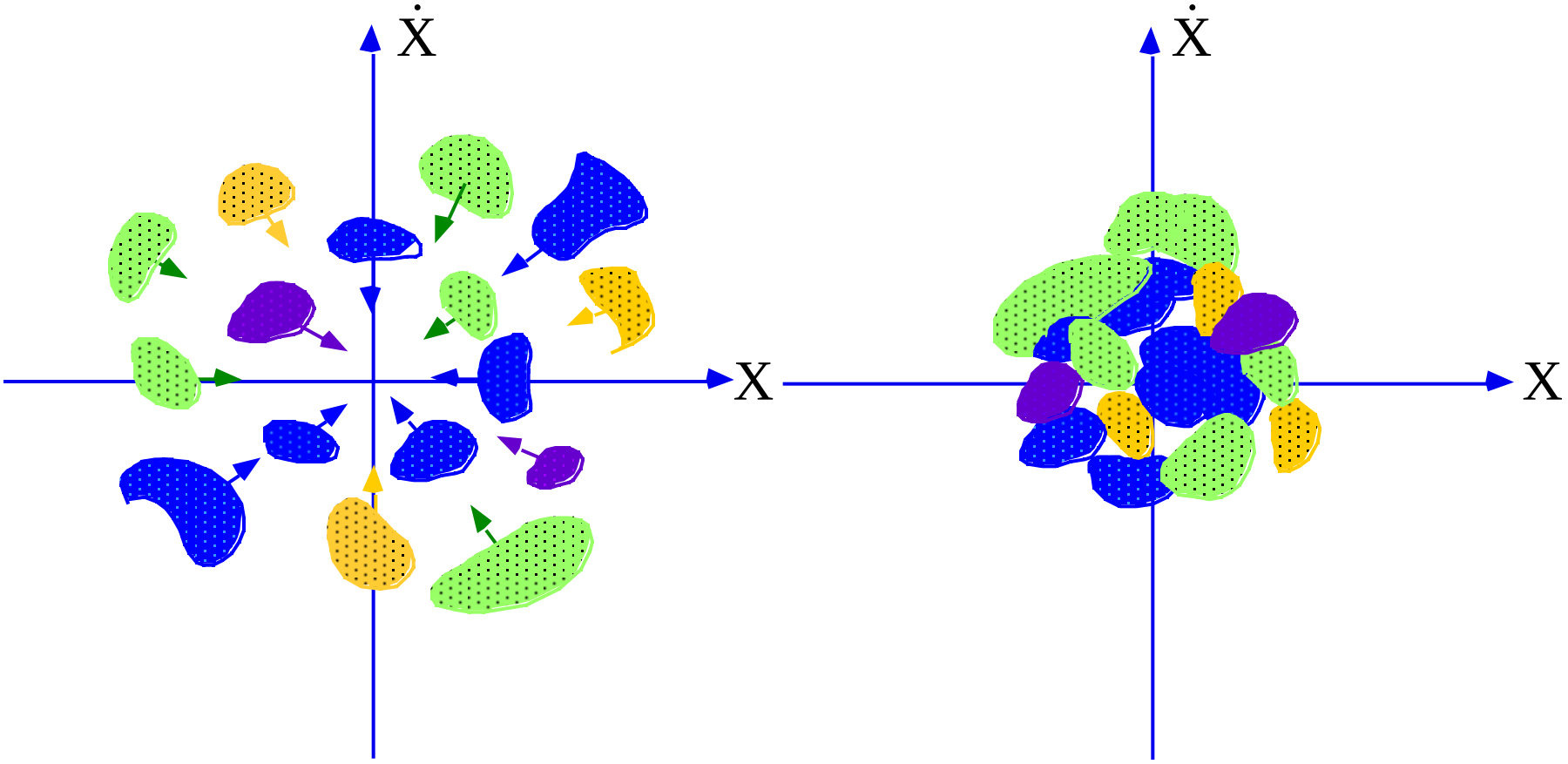
$$\frac{d}{dt}\left[m(S_t)\right] = 0$$



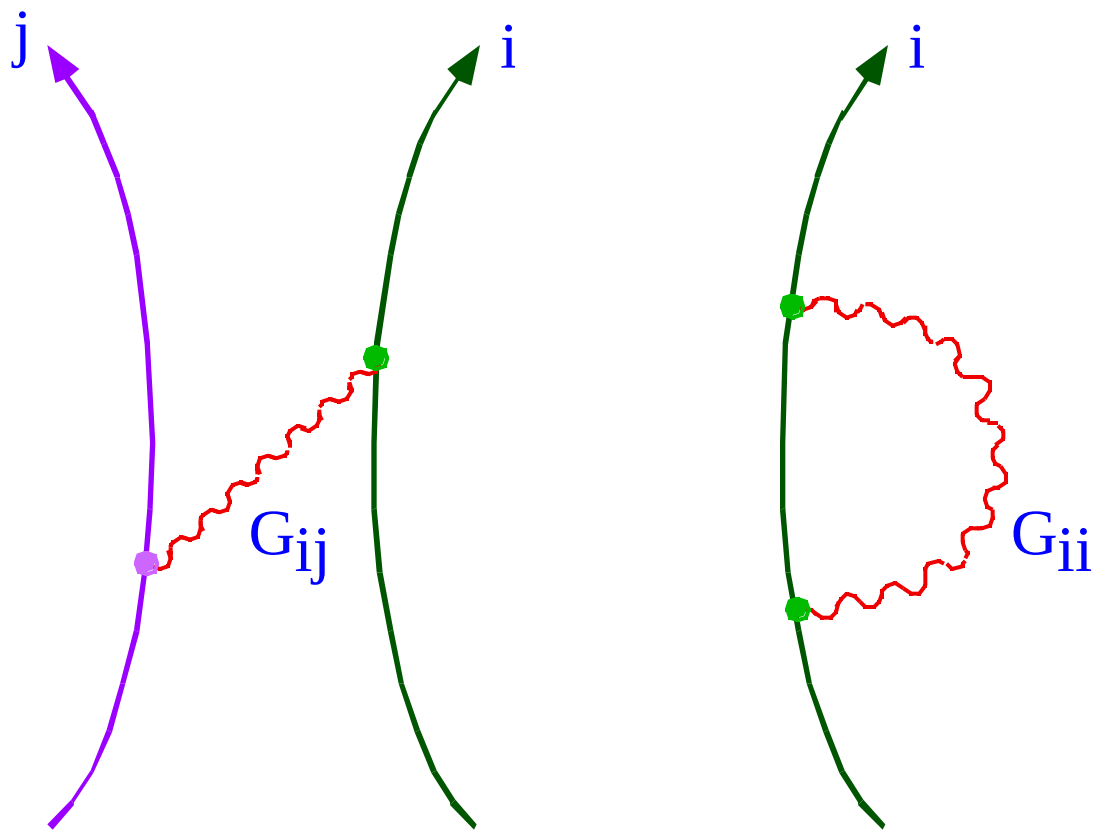
Interaction through the Pick-Up-Amplifier-Kicker Feedback Loop



Phase-Space Cooling in Any One Dimension

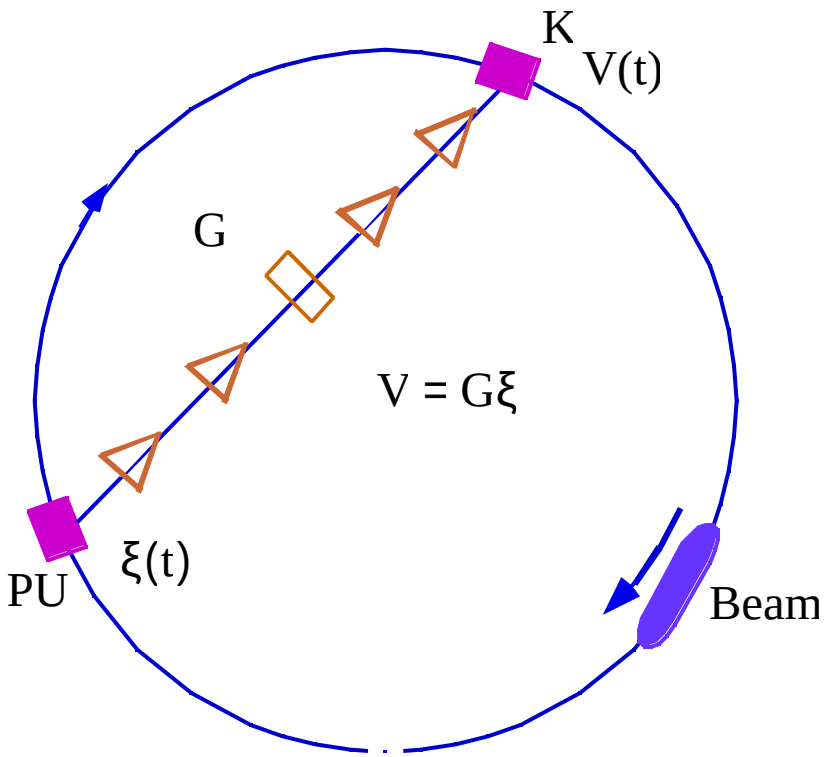


The Two Fundamental processes in Stochastic Cooling
(a) Incoherent Scattering of Two Different Particles and (b) the Self-Interaction Force



Typical Stochastic Cooling Feedback Loop in a Storage Ring

(proposed by S. van der Meer, 1968)



Why Cool?

Average transverse temperature of antiprotons produced by proton beams:

$$\left(kT\right)_{Target} = \frac{\left(p\right)^2}{2m_p} \approx 5x10^6 \text{ eV}$$

where $\langle p \rangle \sim 300 \text{ MeV}/c$

Typical transverse temperature accepted by a high energy storage ring's dynamically available phase-space:

$$\left(kT\right)_{Ring} \sim 1\ 2x10^4 \text{ eV}$$

Need Phase-Space Cooling by many orders of magnitude